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**AMS Tracker Thermal Control Subsystem**

**TTCB DPS Vibration noise  
test summary**

**AMSTR-NLR-TN-057**

**ISSUE 1.0**

**APRIL 2009**

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Sun Yat-Sen University (SYSU)  
National Aerospace Laboratory (NLR)  
Istituto Nazionale di Fisica Nucleare (INFN)

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## Document change log

<u>Change Ref.</u>	<u>Section(s)</u>	<u>Issue 1.0</u>
-	All	Initial issue



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## Summary

This document describes the work performed on the DPS vibration noise detected during TTCB-S Functional testing at AIDC and checks at SYSU (China).

Conclusion is that the noise is most likely caused by the test loop hydraulics. SYSU did not find the noise in their loop with the exact flight lay-out tubing.

The following causes were crossed out by tests and deduction:

- Electromagnetic noise
- Sonic waves in tube segments
- Noise of the climate chamber used during TTCB-S Functional check

Possible causes are:

- Hydraulic vibrations in the loop induced by
  - Pump interaction with pump suction tubing
  - Flow meter mechanics interaction with pump suction tubing

Additional checks will be performed prior to TTCB TV testing in Terni to verify that the noise is not related to box tubing vibrations.



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## 1 Scope of the document

During the TTCB-S functional check a large vibration (noise) peak was found on the output of the DPS sensor. The amplitude of the noise was larger then the maximum span of the normal DPS output. In this document an overview is given of the actions taken, tests performed, results and conclusions.

The same problem was found in the TTCB-P functional check. Because the similarity of the problem the phenomena was only investigated in TTCB-S.

## 2 References documents

RD-1	Title	Number

### 3 Problem description

Noise is detected on the DPS signal when implemented in the box with operating pump.

The noise amplitude is larger than the span of the DPS signal itself. Even amplitudes up to 7 Volts are detected. The frequency is around 200 Hz.

Power outputs	<ul style="list-style-type: none"> <li>• <math>\pm 15 \text{ V}_{\text{DC}}</math>, min. 20 mA (+15V, -15V);</li> <li>• One power return (GND).</li> </ul>
Signal outputs	None
Signal inputs	<ul style="list-style-type: none"> <li>• One analogue input (DPS1_P, DPS1_S);</li> <li>• One signal return (GND).</li> </ul> <p>The pressure signal is an analogue voltage, proportional to pressure. Scaling: 0 Pa <math>\equiv</math> 0 V, 100 kPa <math>\equiv</math> +2.5 V</p>

**Table 3-1: DPS Electronic interface**

During a DPS test with a static pressure difference created by putting different static pressure on either sides. In this static case no noise was detected indicating it is a pump induced phenomena.

We now are trying to find the origin of this noise. It can be:

- Non-Acoustic noise related to the loop dimensions and hydrodynamic characteristics
- Acoustic noise related to the local tubing configuration transfer by fluid
- Acoustic noise related to local tubing configuration transferred by tubing
- Electromagnetic noise

#### 3.1 Important characteristics of the vibrations

The vibrations were detected mainly on the inlet tubing of the pump. Ranging from the box all the way to the hydraulic resistance coil in the ice bath. This coil simulates the pressure drop of the loop and serves as cooling coil to dissipate the pump heat introduced in the loop.

Suspects apart from the pump are:

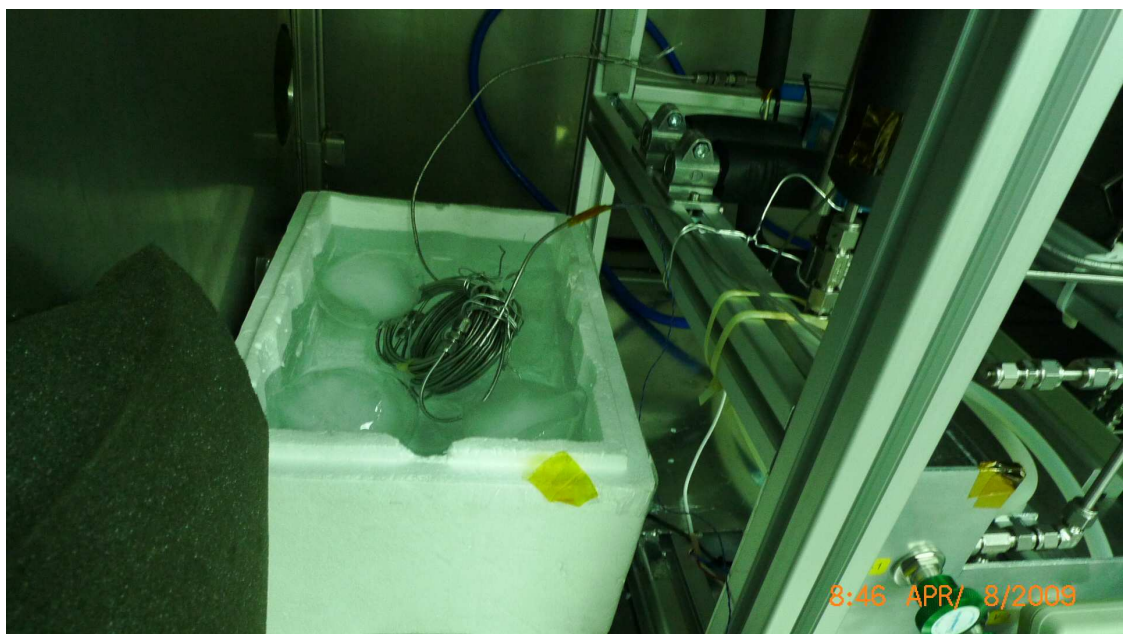
1. Liquid flow Meter (LFM)
  - The noise was present both with an operating and non-operating LFM indicating that no active noise is created by the LFM
  - The LFM flow construction can still be part of the noise problem
2. Coil of tubes just prior to the LFM
  - The mass flow during the TTCB functional test is low compared to the mass flow in the AMS EM loop at SYSU
  - This indicates the resistance is relative high and mainly located just upstream the pump.

### 3. Noise from the climate chamber

- This was checked and proven not to be of influence



**Figure 3-1: TTCB-S Functional Test set-up**



**Figure 3-2: TTCB-S Functional Test set-up detail; coil and upstream TC**



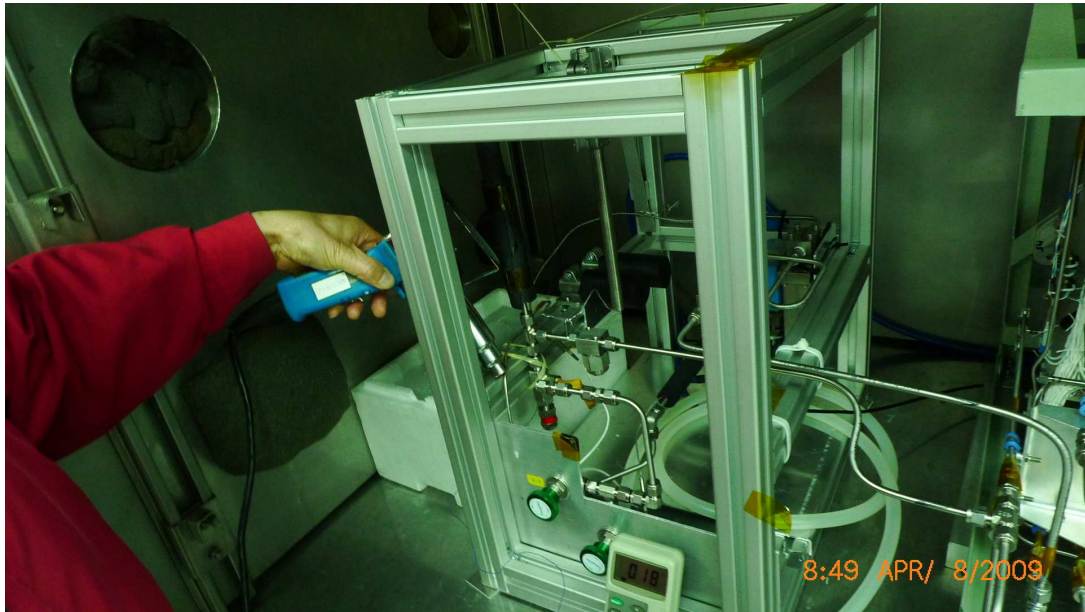


Figure 3-3: TTCB-S Functional Test set-up detail; heating with heat gun



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### 4 Experiment plan to check problem causes

In the following actions are defined to discriminate between the options.

We would like also to understand what kind of frequencies can be measured by the sensor. So first a question to CETC (DPS Supplier).

#### A. DPS bandwidth (CETC) Action SYSU

In order to discriminate between several options we would like to know if CETC has an idea of the mechanical and electrical bandwidth of the DPS sensor. Please ask the same also for the APS (see point C below).

NLR found in the specifications of an ordinary APS 400 Hz bandwidth but it changes between types. However this indicates that it is very likely that DPS sensor will be susceptible to the detected frequency.

Then the test actions.

#### B. DPS Signal verification at SYSU EM-loop (discrimination between 1 versus 2,3,4) Action SYSU

Could you put a scope on the DPS signal to see if we have the same phenomena on the TTCS EM loop. This is proposed by Aswin etc also I think.

First with only fluid.

Second also with two-phase flow and check if you find changes.

Results can be found in Appendix D. No noise is detected in the EM-loop at Sun Yat Sen University which is complete similar to the TTCS flight loop. This indicates the induced noise is test loop related and in Flight we will not suffer from these vibrations.

#### C. APS signal check at AIDC TTCB-S (discrimination between 1,4 versus 2,3) Action @ AIDC by Aswin, Vladimir, Andy

Check with a scope the APS signal to see if you find also a ripple on this signal with the same frequency dependence.

If similar ripples are detected it is likely that the noise is system related then induced by tubing configuration.

Result is that no ripple with the same impact as for the DPS was found. However the noise is felt on the tubes so it is very likely a difference in "reception" bandwidth of the sensor.



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## **D. Induce noise on the tubing TTCB-S (discrimination between 1,2,3 versus 4) Action @ AIDC by Aswin, Vladimir, Andy**

Make noise on the tubes and check if you find it back in the DPS signal

This test has been performed. Noise (of different frequency) has been introduced on the tubes and could be measured with the DPS indicating that the tube or the fluid can conduct the noise. However the noise does not have the same frequency as the original DPS noise.

## **E. Induce a vapour section in the TTCB-S or tubing (discrimination between 1 versus 2) Action @ AIDC by Aswin, Vladimir, Andy**

Create a vapour bubble in the loop by the start-up heater or pre-heaters and check if DPS signal noise is changing.

This was performed with the pre-heater section. However no noise reduction was measured. As this vapour section was hydrodynamically far away from the vibration point (Large resistance coil, Flow meter and pump inlet section) a second attempt was done by introducing vapour just prior to the resistance coil. This is described in Appendix G. However also this did not reduce the noise.

## **F. Induce noise on the tubing with empty TTCB-P (discrimination between 2 versus 3) Action @ AIDC by Aswin, Vladimir, Andy**

Induce noise on tubing with empty loop and without pump running and check if you see DPS signal changes. This will show if the tubing or the fluid is transferring the noise.

Also in this case the noise was conducted to the DPS. Conclusion is that the tubes can conduct the vibration but it does not mean exclusively tubing.

For your information:

From previous problems NLR detected with a gear pump (larger pressure pulses than centrifugal pumps) in our loop the noise was transferred by the fluid. When we created bubbles at the inlets of the DPS the noise was reduced



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### **5 Conclusions and how to proceed**

Conclusion is that the noise is most likely caused by the test loop hydraulics. SYSU did not find the noise in their loop with the exact flight lay-out tubing.

The following causes were crossed out by tests and deduction:

- Electromagnetic noise
- Sonic waves in tube segments
- Noise of the climate chamber used during TTCB-S Functional check

Possible causes are:

- Hydraulic vibrations in the loop induced by
  - Pump interaction with pump suction tubing (coil)
  - Flow meter mechanics interaction with pump suction tubing (coil)

Additional checks will be performed prior to TTCB TV testing in Terni to verify that the noise is not related to box tubing vibrations. It is expected that no vibrations will be present.



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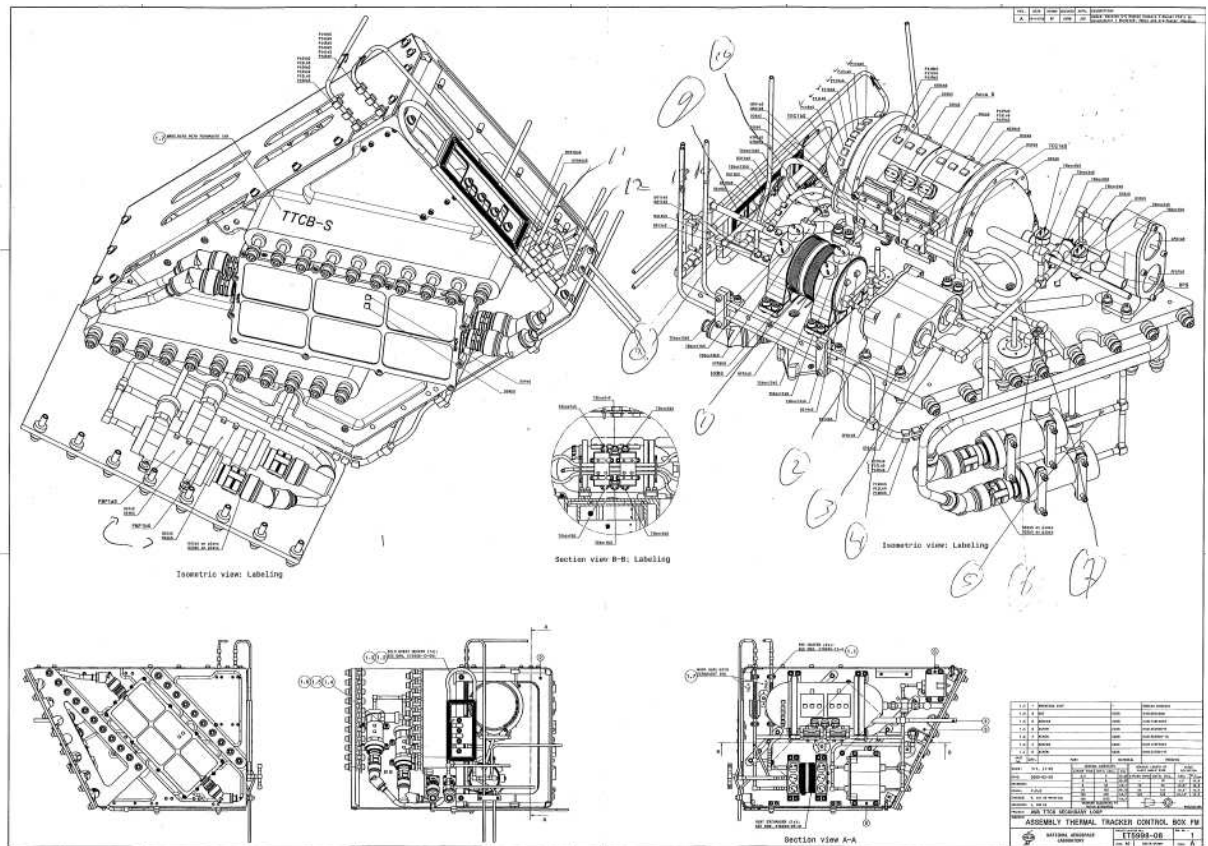
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## Appendix A: TTCB-S Overview





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### Appendix B AMS02: Analysis of ripple in DPS signal

M. Bardet, 31/3/2009

Looking at the four plots attached to Andy's e-mail of 31/3/09, I do not find a clear correlation between the pump motor speed and the measured AC signal.

My observations are the following:

Pump RPM	Pump rotation period	Signal in plot period	Remarks
2500	24 ms	5.7 ms	Relatively small AC component
5000	12 ms	26 ms	Strong harmonic at 192 Hz
7500	8 ms	15 ms	Strong harmonic at 207 Hz
10000	6 ms	14 ms	Strong harmonic at 150 Hz

Is it known how accurately the pump RPM was measured?

My initial impression is that the large AC pressure variations that we observe are related to resonance in the liquid system (or even in the DPS itself) that is excited by some specific pump rotation frequencies. The Eigen frequency seems to lie close to 200 Hz. This could be an explanation for the very large "harmonics" that occur at most pump RPM settings.

If it is indeed liquid resonance that is causing this behaviour, then it should be very sensitive to the quality of the CO<sub>2</sub>. Gas in the system tends to damp such pressure waves effectively.

This could even be an explanation for the very different response that we see at 2500 Hz, where the AC component looks much like a sine wave and has relatively small amplitude.

My proposal is to determine where this phenomenon occurs. If there are indeed pressure waves going through the system then something should be done to avoid this.



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If it seems like the DPS itself is causing the disturbances then this should be further investigated. Does the APS give an AC component in its output signal?

I do not recommend to put effort into electrically filtering the DPS signal if it is giving these excessively large AC output signals. Note that we are working outside of the specified operating range of the DPS too! We do not know if the DPS response is still linear, and in the cause of time the DPS (and/or pump, valves) may even be damaged.





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## Appendix D: Tube vibration frequency check

H.J. van Gerner:

As it looks like the noise has an acoustic origin we checked in the design to see which tubing could cause vibrations.

Our new thermal group member Henk Jan van Gerner performed some calculations to see if the tubes could be in a Eigen-frequency.

### Rough order check of frequencies and prime suspect

The high amplitude 200 Hz signal might be caused by tubes vibrating in their natural modes, since the natural frequency of the tubes is of the same order as 200Hz (see equations below).

The 2 tube sections which are the most suspicious are

- The attachment of the DPS to the Peltier tube (location 1)
- The combined inlet tube of the pump (larger unsupported length) connected to the DPS (locations 2 and 3)

### Checking the suspects

Fortunately, if resonating tubing is the cause for the problem, it can be fixed relative easily. The lateral freedom of motion of the tubes can be restricted by placing wedges between the tube and a nearby plate. In the attached pdf file, the location are indicated with an encircled 1, 2 and 3.

- At 1, the wedge should be placed further to the bend of the tube than indicated in the drawing (although the precise location is not so critical)
- At 2, the wedge can be placed between the tube and the dummy plate.
- At 3, the wedge can be placed between the two tubes.

The wedges can be made of any material (plastic, rubber, steel) as long as they prevent the lateral motion of the tube. However don't damage the base plate please!

I hope above is clear. I hope the box is at ambient conditions so you can access the locations easily.

If you can run the loop in ambient you could also just check the above by holding the tubes sections by hand.

Below you find the frequency calculations.

### Unlikely other suspect

If the above is checked but not the cause it could be cavitation at the pump outlet 90 degree bends but that is very unlikely. Running the loop with extreme subcooling is then an option.

### Frequency of tubes

The lowest natural mode a tube that is pinned on both sides can be calculated with

$$\omega = \pi^2 / L^2 \sqrt{E I / m}$$





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$$f = \omega / (2\pi)$$

with:

$$I = \pi / 64 * (d_{out}^4 - d_{in}^4); \text{ \% Bending stiffness}$$

$$A = \pi / 4 * (d_{out}^2 - d_{in}^2) \text{ \% cross section area}$$

$$m = A * \rho \text{ \% mass per unit length}$$

Applying the relevant numbers:

$$d_{out} = 6e-3 \text{ \% outer diameter tube}$$

$$d_{in} = 4e-3 \text{ \% inner diameter}$$

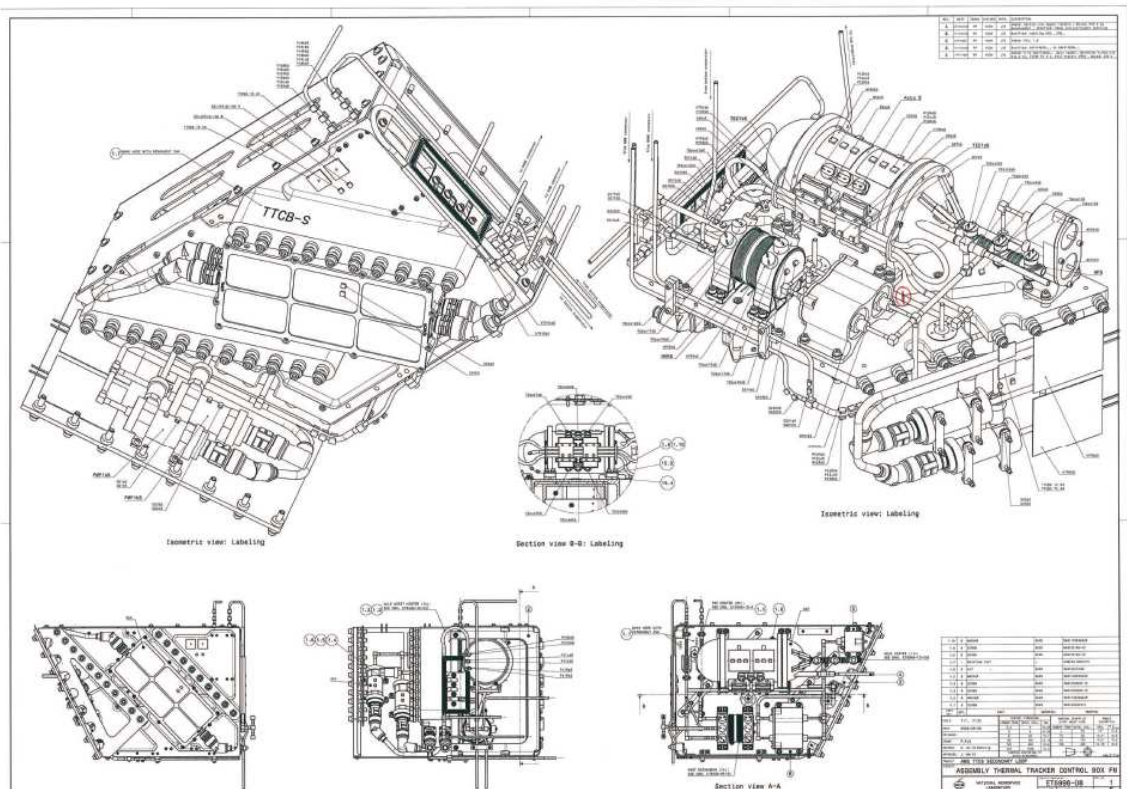
$$L = 0.15; \text{ \% length of tube}$$

$$\rho = 7850 \text{ \% density steel}$$

$$E = 200e9 \text{ \% elasticity modulus steel}$$

yields a frequency of approximately 600 Hz. A tubing length of 25 cm yield a frequency of 200Hz

Proposed wedge locations





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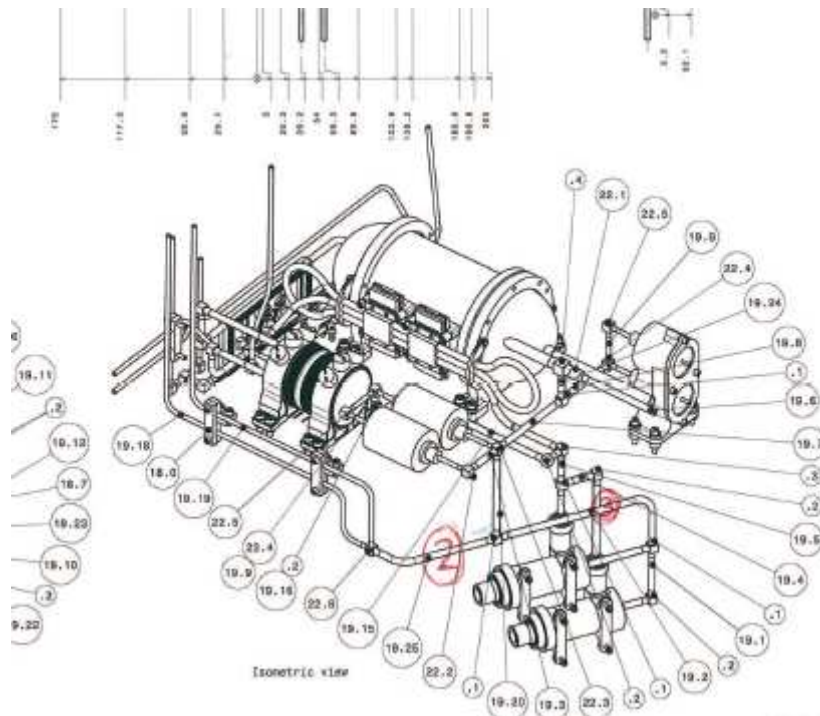
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## Appendix D: AMS02: Ripple check with TTCS EM-loop at Sun Yat Sen University

Below you find the photos of the test signals of DPS with different pump speeds, displayed by an oscillograph. The photo name is combined with two parts, e.g. "5000rpm(20 $\mu$ s)". The first part is pump speed and the last part in parentheses is the deltaT of the oscillograph.

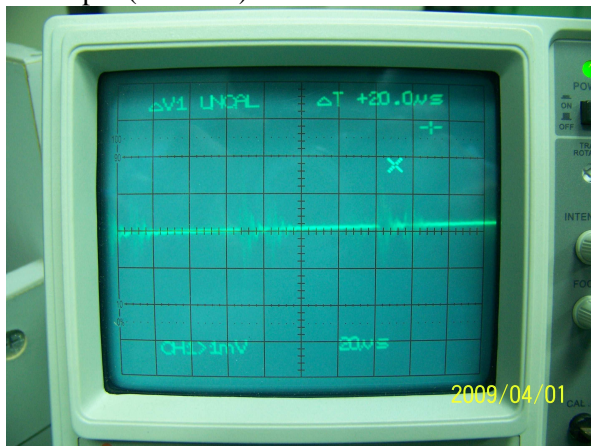
Zhou Jinpeng

### Conclusion and interpretation

The results show that no similar ripple is found with the tests in the final loop lay-out at SYSU. The ripples shown below is only HF-noise and is a factor 100-1000 smaller then the normal DPS-signal.



3000 rpm (2 micros)



3000 rpm (20 micros)



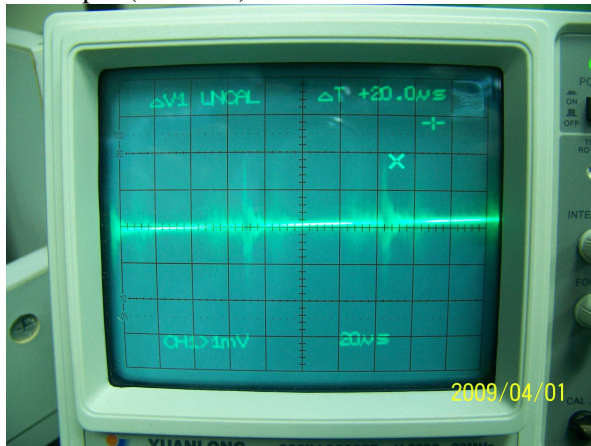
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5000 rpm (2 micros)



5000 rpm (20 micros)



7500 rpm (2 micros)

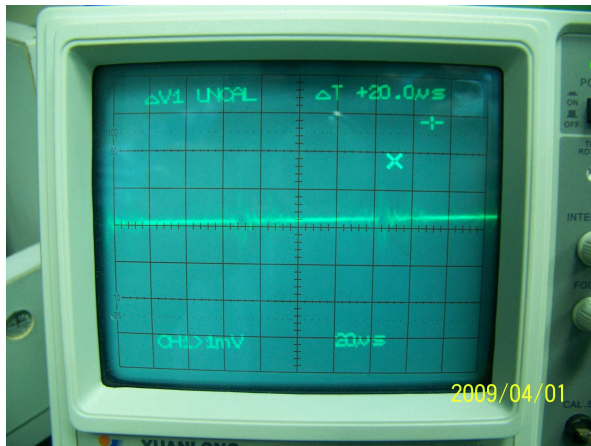




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7500 rpm (20 micros)



10000 rpm (2 micros)



10000 rpm (20 micros)



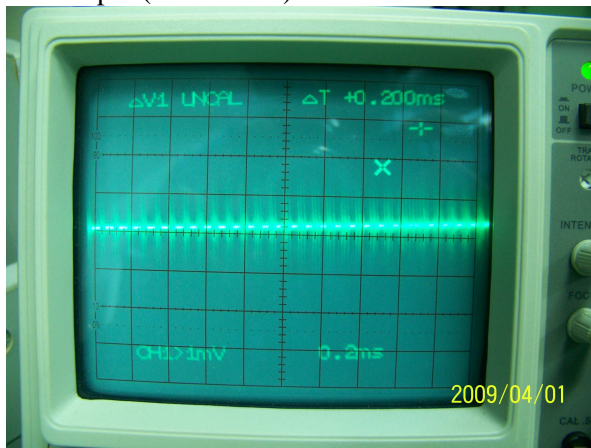
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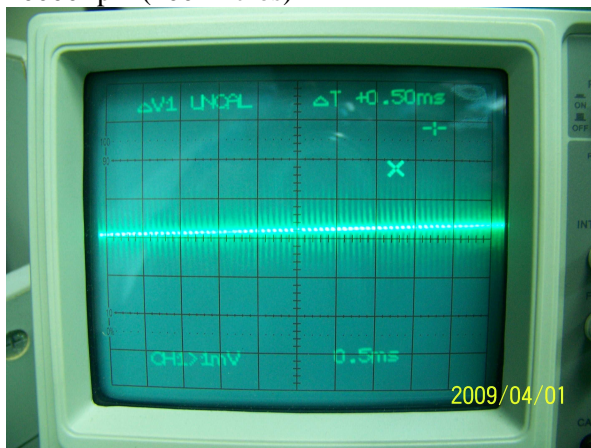
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10000 rpm (100 micros)



10000 rpm (200 micros)



10000 rpm (500 micros)



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## Appendix E: Oscillation dependence of frequency

V. Koutsenko:

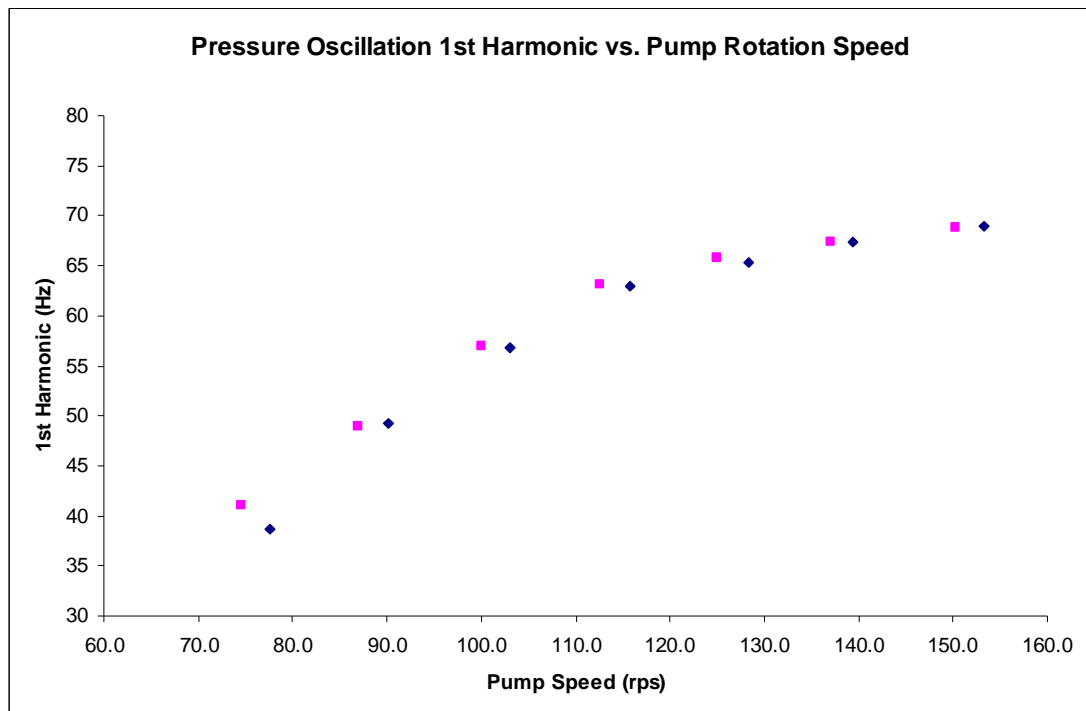
It was found at test setup for TTCB that there is CO<sub>2</sub> pressure oscillation detected by DPS.

Pressure oscillation amplitude exceeds DPS dynamic range (2.5 bar).

Please find in the attachment dependence of pressure oscillation 1st harmonic vs. pump rotation speed.

1st harmonic was measured by HP spectrum analyzer.

There are two sets for set point 22°C and 18°C.





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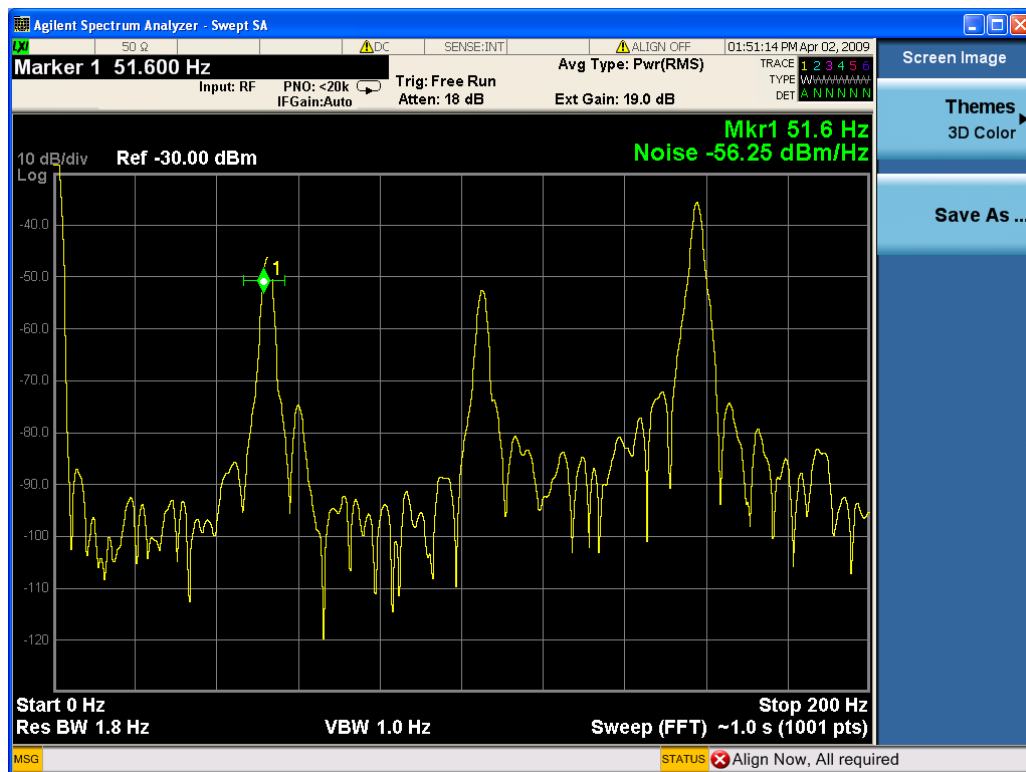
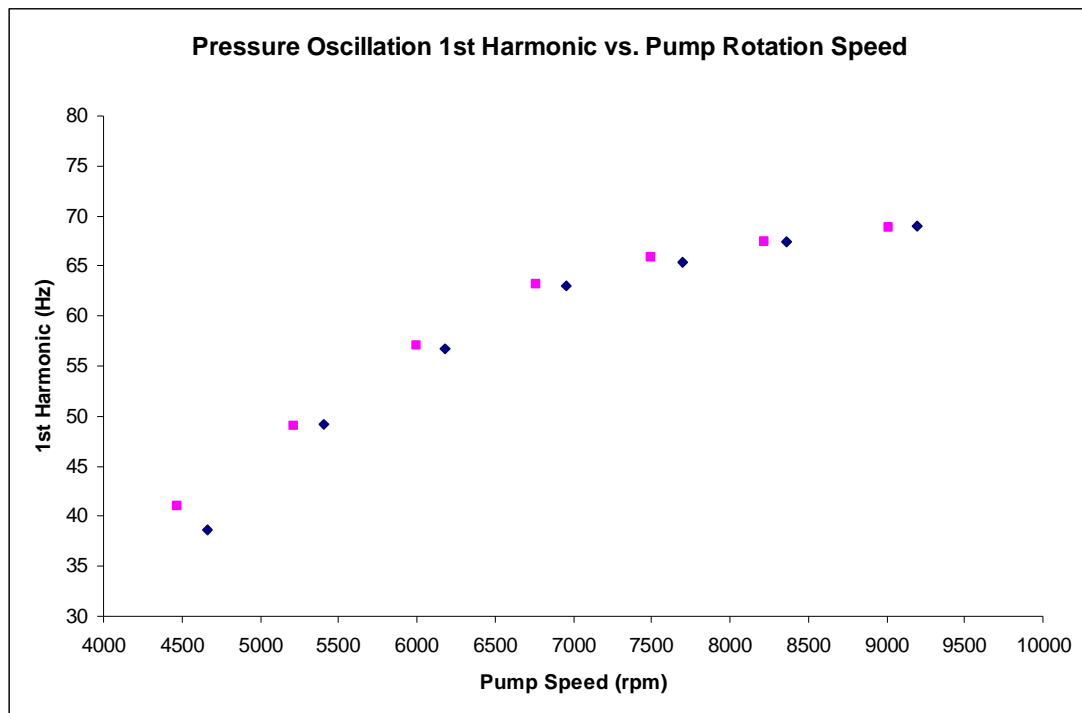
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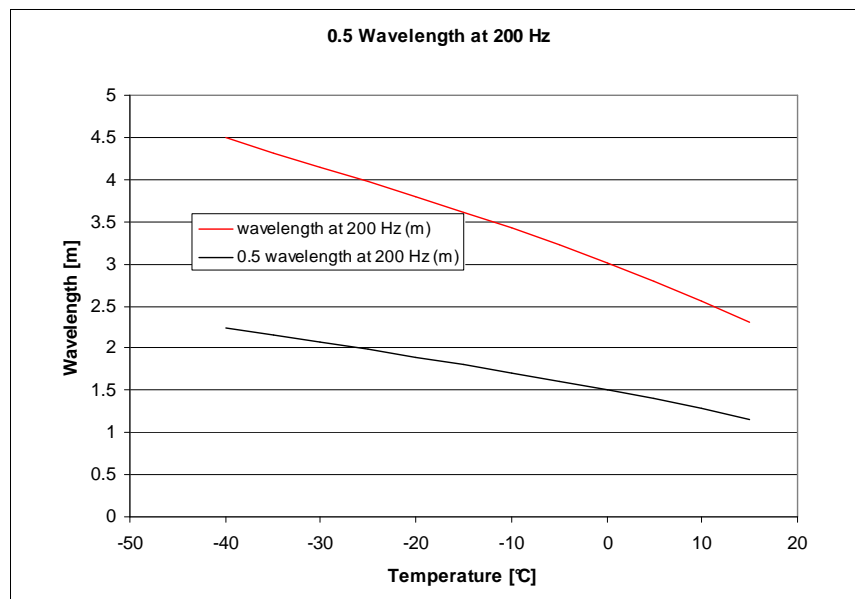
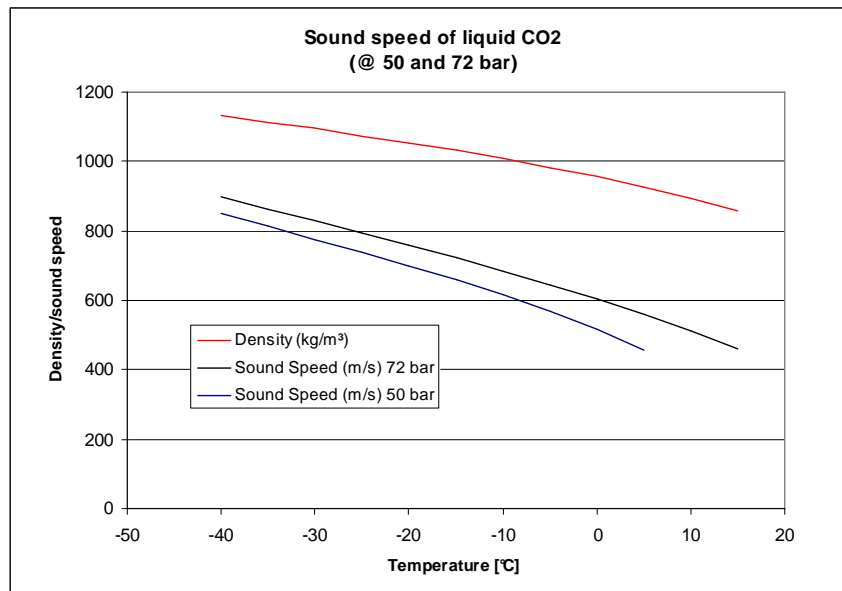
Typical cross correlation DPS noisy signal. In above graphs the first harmonic is shown (indicated with green marker)



## Appendix F: Sonic wavelength estimation in CO<sub>2</sub>

G. van Donk

A calculation of the speed of sound has been made as function of temperature. The corresponding half wavelengths at 200 Hz are shown. The values are all above 1 meter. It is therefore unlikely that a sonic wave will be present in the loop as the characteristic loop length of the tubes are a factor 5 or more lower than 1 meter. For lower frequencies (e.g. 65 Hz) the wavelength will even further increase (3.6 m half wavelength).





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## Appendix G: Vapour damping test TTCB-S

Raki Huang

On 7 and 8 April 2009 additional test were done at AIDC to check if a vapour section could have influence on the DPS noise level.

### Objective

Check the influence of a vapour section close to the possible vibrations source (coil, flow sensor assy and inlet section pump). Test performed last week had only vapour further away from (upstream) the source.

The DPS 2-phase test data is as below:

Initial condition:

Taccu = 22.06 C

Tinlet\_pump = 21.62 C

Tpump : DS1BS = 21.19 C, DS2BS = 21.31 C

Set climate chamber to 18 C

B side pump using. When the conditions as below are satisfied, pump started.

Taccu = 22.0 °C, Tinlet (Pt2) = 17.25 °C, Tmpm(DS1BS) = 18.69 °C

Pump Voltage (mV)	RPM	Flow Rate (g/s)	Refer to
Find max RPM without oscillation DPS output (No heat gun)			
1136	3820~3946	0.788	DPS_Signal_2Phase_Test_01.TIF
1152	3846~3980	0.800	DPS_Signal_2Phase_Test_02.TIF
1168	3933~4059	0.832	DPS_Signal_2Phase_Test_03.TIF
Heat up coil with heat gun			
1136	3886~3966	0.595	DPS_Signal_2Phase_Test_04.TIF
1232	4073~4166	0.766	DPS_Signal_2Phase_Test_05.TIF
1344	4480~4613	0.999	DPS_Signal_2Phase_Test_06.TIF
1520	4980~5053	1.082	DPS_Signal_2Phase_Test_07.TIF
1600	5160~5240	1.170	DPS_Signal_2Phase_Test_08.TIF
1644	5580~5673	1.253	DPS_Signal_2Phase_Test_09.TIF



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1824	5926~6026	1.39	DPS_Signal_2Phase_Test_10.TIF
	About 7500		DPS_Signal_2Phase_Test_11.TIF
	About 10000		DPS_Signal_2Phase_Test_12.TIF

The vibration seems to reduce when pump RPM changed from 5000 to 5200 (figure 7 & 8) until 6000, after that, the vibration becomes bigger.

## Additional test with Vapour test upstream hydraulic resistance coil (08/04/2009)

1. **Set-up small addition/adaptation**
  - a. Be sure of two-phase flow
  - b. Check two-phase with TC downstream the blower
2. **Sequence change**
  - a. Start with single phase flow
  - b. Store DPS output
  - c. Create two-phase flow by heat gun
  - d. Store DPS output

Use heater of the pump test set-up to heat up the flow

$$R = 4.8 \text{ Ohm}$$

$$\text{Power} = V^2/R \rightarrow V = 15 \text{ Volt} \quad P = 46.8 \text{ Watt}$$

$$I = P/V = 46.8/15 = 3.12 \text{ A}$$

$$\text{Mass flow} * \text{latent heat} * \text{quality} = 0.8 * 10^{-3} \text{ kg/s} * 1.86 * 10^5 \text{ J/kg} * \Delta T = \text{Power}$$

$$\Delta T = 1 \rightarrow 148.8 \text{ W}$$

$$X = 0.31$$

$$3.41 * 10^3 \text{ J/kg/K}$$

$$P = \text{mass flow} * C_p * \Delta T = 16 \text{ W}$$

## Results comparison between liquid and two-phase flow

1. **4000 rpm**
2. **7500 rpm**
3. **10000 rpm**



# AMS Tracker Thermal Control Subsystem

TTCB DPS Vibration noise test

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Issue

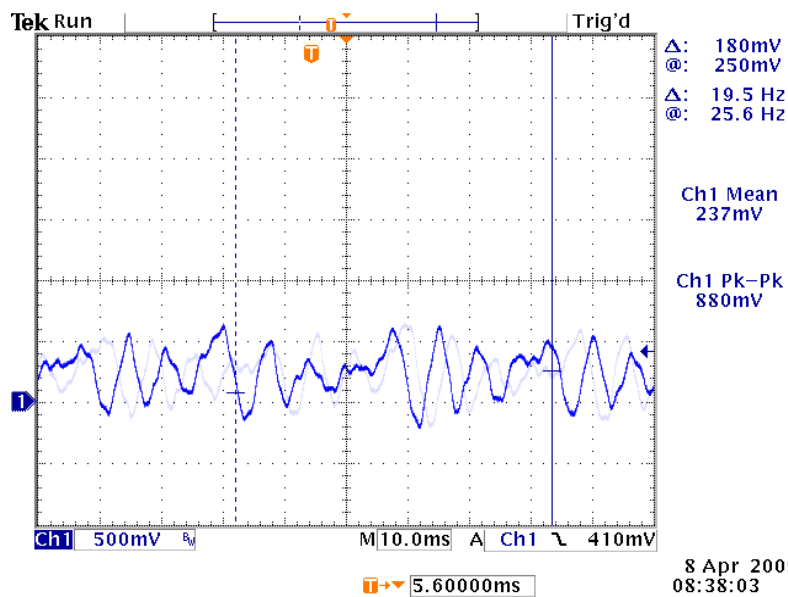
Date

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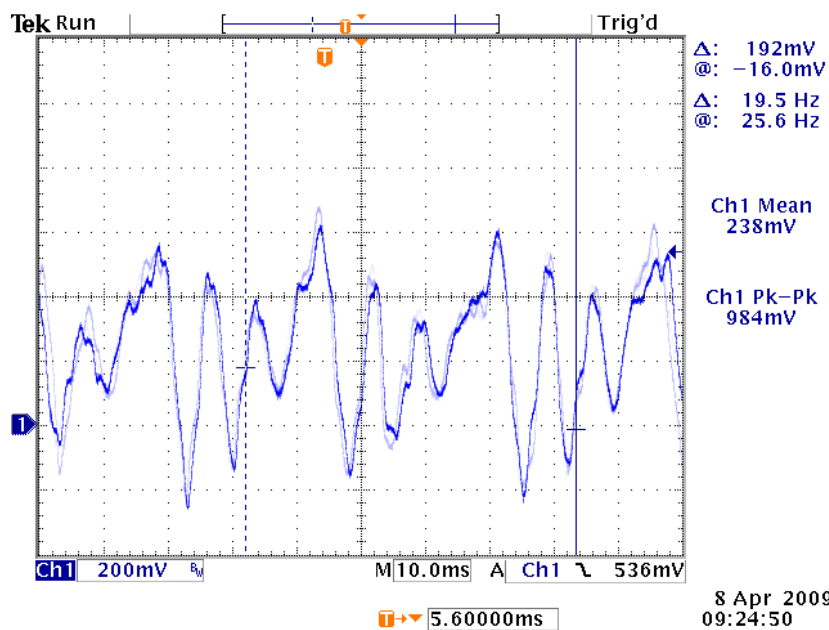
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Liquid flow 4000 rpm



Two-phase upstream coil 4000 rpm



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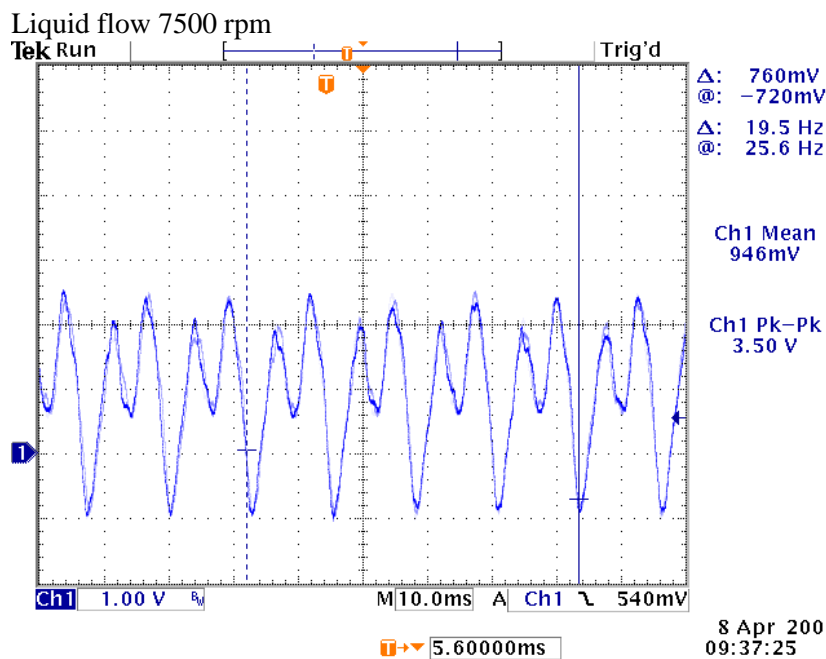
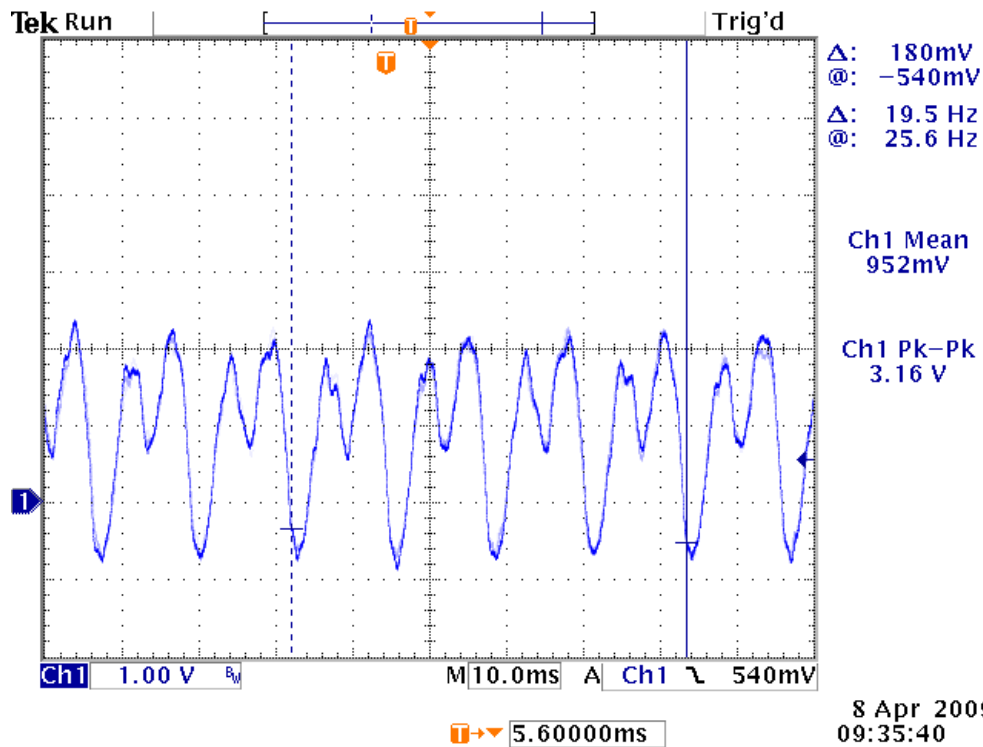
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Two-phase upstream coil 7500 rpm



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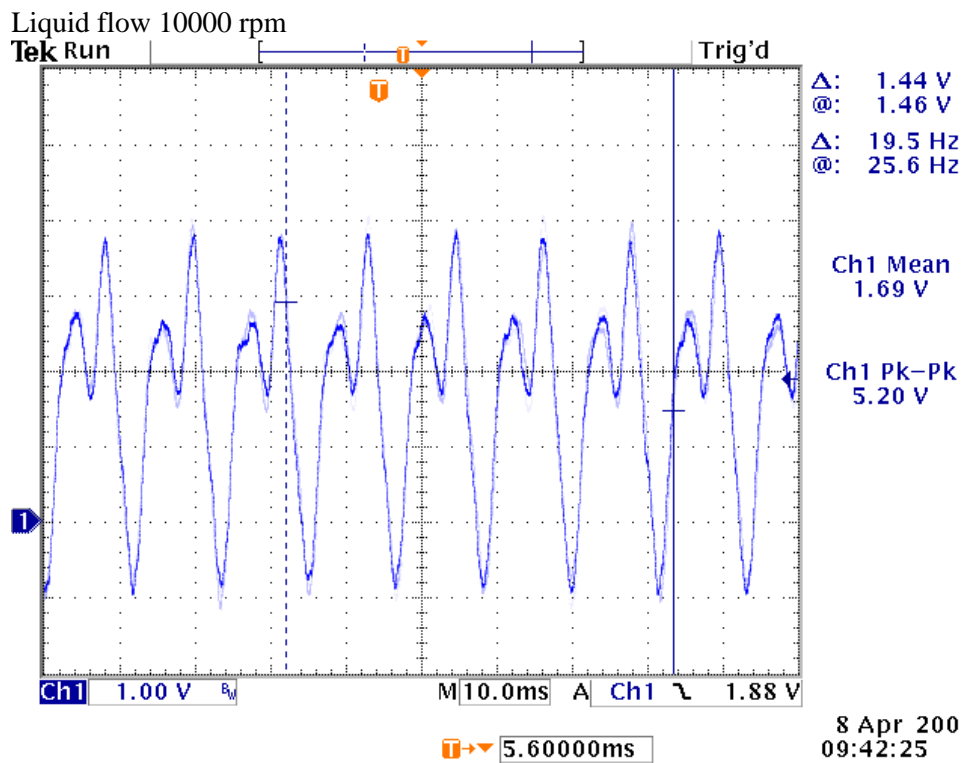
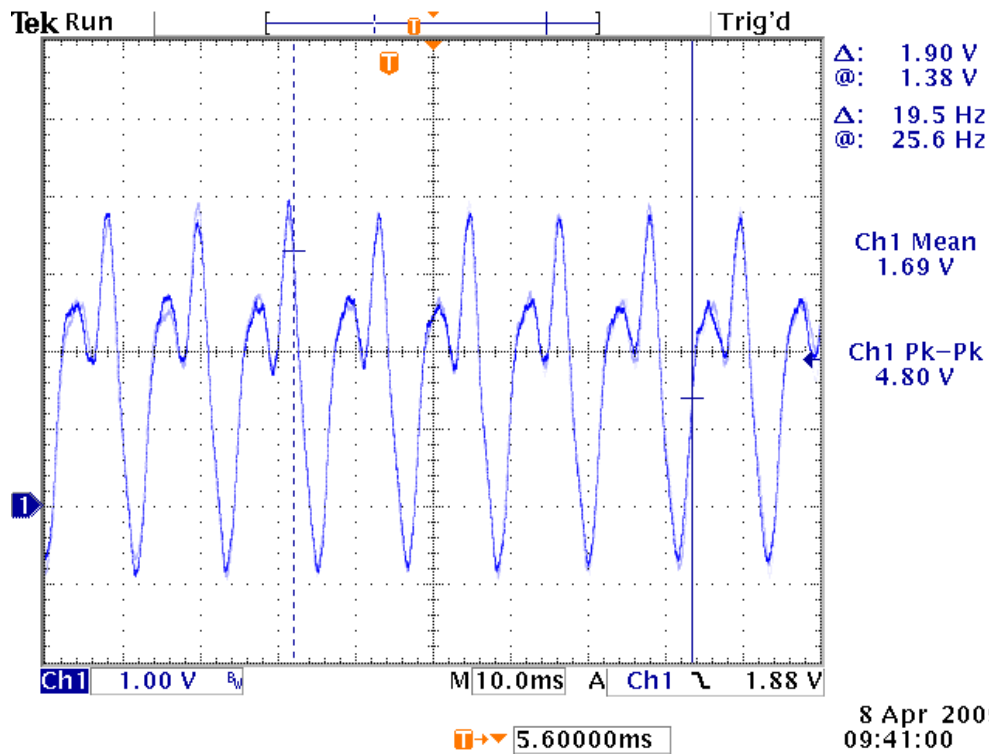
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Two-phase upstream coil 10000 rpm



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